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USES OF HOLOGRAPHY IN MICROELECTRONICS

by

Andrzej Kalestynski

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By: Andrzej Kalestynski

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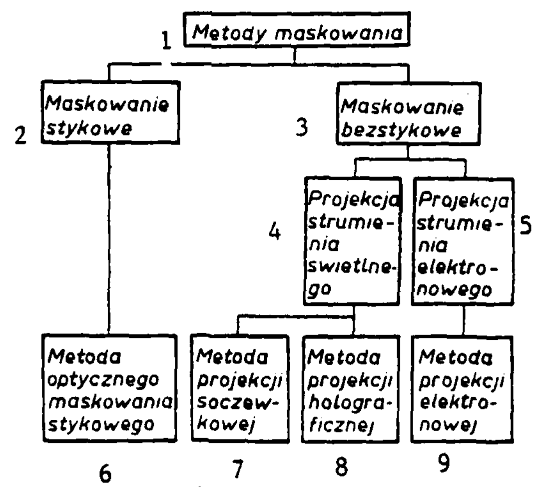
Uses of Holography in Microelectronics

In semiconductor electronic technology photolithography and, above all, masking are an important part of the process of proc :tion of microelectronic elements. The purpose of masking is a precise transfer of the pattern of a mask which consists, for instance, of transistor fragments or integrated systems to a silicon plate of the foundation. For producing for instance one integrated circuit several maskings are needed dependent upon the degree of integration, (usually around 10 processes.) Masking is conducted with the use of precise instruments which in the Polish literature are defined by the term "masker". Figure 1 lists methods of masking which are currently used in production, or which are being worked out in laboratories (and) which in the near future will enter production. The method of holographic masking should be counted among non-contact masking which uses projection with a light stream. In other solutions non-contact masking takes advantage of the projection with an electron stream. The task of non-contact



Rys. 1. Różne metody maskowania

Fig. 1. Various methods of masking: 1 - methods of masking. 2 - contact masking. 3 - non-contact masking. 4 - projection of a light stream. 5 - projection of an electron stream. 6 - method of optic contact masking. 7 - method of lense projection. 8 - method of holographic projection. 9 - method of electron projection.

masking (just as of contact masking) is a transfer of a mask pattern on the photoresist which covers a silicon plate, but unlike in contact masking this goal is attained without the mask and photoresist being brought into contact. The interest in methods of non-contact masking is the result of a short life expectancy of a costly mask which sometimes does not surpass 10 maskings.

The following methods belong to a method of non-contact masking which use projection with light radiation:

- the method of lense projection
- the method of holographic projection.

For the purpose of getting oriented in the advantages of holographic projection in comparison to lense projection it is worthwhile to get acquainted with the later.

The Method of Lense Projection

In this method a special optic system facilitates a non-contact transfer of the picture of the mask to a photoresist after previous adjustment of a semiconductor plate with a mask, with the aid of a micromanipulator. The distance between a mask and a plate is at a level of some scores of centimeters. Because of this one avoids fast destruction of an expensive mask.

This type of a solution places high demands on a projecting system which should be characterized by a high accuracy of a reproduction in a large field of vision; (generally dimensions of a mask are 50 X 50 mm, but there are nedeavors to increase their areas even to 75 X 75 mm.) The distributive capacity of a projective system in the entire field of a mask should be several hundred lines per milimeter with the total aberration correction. Even if one bypasses the problem of the correction of diffraction effects which are results of bending of ultraviolet radiation used in projection on a small pattern of a micromask, the problem of ensuring high quality of optic elements of projecting system with a large field of vision is unusually difficult. Although on the world market there are lense maskers of Japanese American and West German production, yet given their defects and high prices they have difficulties in competing with contact maskers. The scope of those difficulties is demonstrated by the compendium of characteristics of the best lenses produced by a world famous Japanese company enclosed

in the table.

Also lense maskers for projective masking type "an eye of a fly" have been constructed. They are used for a multiplication of one or several modules of a micromask in one exposure through a multi-lense optic system. However, they did not catch on because of the difficulties in construction and a high cost of the entire instrument.

Ultra-micro Niccon lenses

Type of a lense lense diameter ⌀mm	ʃ mm	Splitting capacity 1/mm	Diameter of a field of work ⌀mm
30	1.2	1200	2
135	4.0	330	50
155	5.6	200	80

Methods of Holographic Masking

For several years scientific and industrial laboratories abroad and also in Poland (in the Institute of Physics of Warsaw Polytechnics) have engaged in research into possibilities of the application of holography in the process of micro-electronic photolithigraphy; above all for masking. Although up until now none of the leading companies constructing contact or non-contact maskers has offered holographic maskers (or holomaskers) for sale on the world market, nevertheless on the basis of the literature one can conclude that in the forthcoming years holomaskers will be produced serially and they will supersede hitherto produced contact and non-contact lense maskers. Currently, such companies as SERL, (Services Electronic Research Company) and Siemens have exhibited laboratory models of holomaskers on world exhibitions.

A holomasker in a most general case consists of two parts: A system for making holograms of micromasks, which from now on will be called holomasks, (fig. 2), and a holographic projector for masking. (Fig. 3.) For creating masks -just as in other disciplines of holography - one uses laser light which, while moving through the optic (beam; Tr.) splitter divides into two beams, according to a scheme elaborated by E. Leith and J. Upatnieks. One beam goes through a master copy of

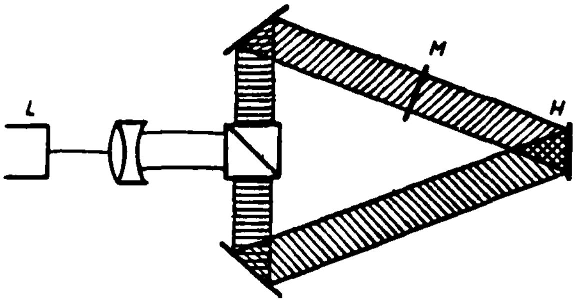


Fig. 2. A scheme of the operation of an
instrument for recording holomasks:
L - a laser, M - a matrix of a micromask,
H - a hologram.

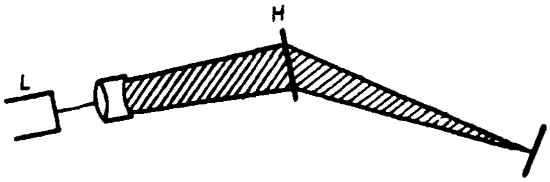


Fig. 3. A scheme of the operation of a holographic
projector of micromasks, (a zero beam and the second
bent beam which carries the imaginary picture are not
shown): L - a laser, H - a holomask.

of a mask M which is the source of informations about a micro-pattern and moves further toward a plate with a photosensitive material, for instance with an appropriate photographic plate which, above all, has a high distributive capacities. The second beam, so called reference beam also falls on a photosensitive material. In the area of the overlap of the information and reference beams their interference takes place, owing to which the full information about the pattern of the micromask is registered. This information is expressed in characteristic interference streaks which correspond to thickening and thinning of the energy of the light field in the area of the overlap of the beams. In the shape of these streaks

a coded information about both the information wave and reference wave is contained.

Reproduction of the informations about a micropattern is obtained through illuminating the holomask by a beam of laser light.

Reproducing reveals one of the advantages of holographic masking, namely the lack of contact, since a sharp and real picture of micropatterns is obtained in a definite distance from the holomask where a semiconductor plate with the photoresist is placed.

The second advantage under those conditions is the durability of the holomask, and the matrix of the micromask itself which is used only in the process of creating a hologram can be stored as a practically indestructible master copy. Among other advantages one has to underline the possibility of holographing an object in a large field of vision with a constant distributive capacity. An important advantage of holomasks which is not encountered in any of the previous methods of masking, (including lense projection,) is a possibility of diminishing reproduced pictures of micropatterns through the use of different wave length in the process of the production of a holomask and in the process of its reproduction. For example, creating a holomask in a field of vision of a helium-neon He-Ne (λ_1=635nm) laser, and reproducing it in the field of vision on an argon Ar (λ_2=488nm), one can obtain a diminished picture (by a ratio of λ_2/λ_1). It is important, inasmuch as the process of recording a hologram can begin with patterns which are larger than those needed in the process of masking itself. Possibilities of its increase by the means of the density of packing of the elements of micromdules arise. One has to emphasise that currently among serious obstacles in successful solving of (problems of. Tr.) constructing industrial holomaskers one has to count the lack of lasers with an appropriate power in which the maximum of radiation would fall within the scope of the spectral color sensitivity of photoresists used in technology, (λ<430nm). Because of the width of the line, (a large distributive capacity matters,) into considerations enter above all continuous beam lasers. To an Ar laser which using high power sends out radiation with the wavelength of λ=488nm spectral sensitivity of a photoresist does not correspond; and current He-Cd (λ=442nm) lasers have too low power. High power of lasers also has significance in reproducing, for a hologram is a sort of diffractive net with a very

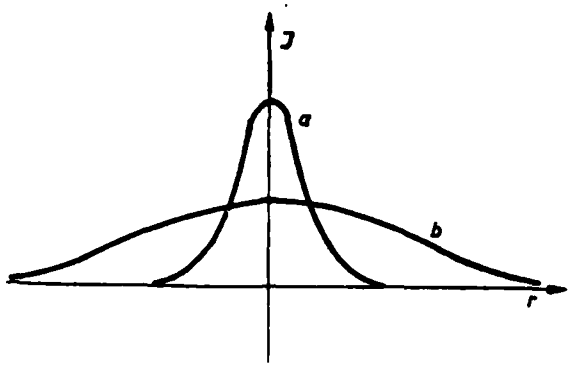


Fig. 4. a) A distribution of intensity in beam of a laser working in the mode TEM_{00},
b) flatening of the distribution of intensity caused by widening the beam.
I - light intensity

complicated structure, in which a pictorial information is carried by a bent beam carrying only a part of the energy falling on a hologram. Productivity of the best holograms, so called amplitude (holograms. Tr.) created on photographic plates reaches 7%, of thin, phase holograms 20% and of reflection holograms 40%. Because of that, the centers dealing with holomasks are also undertaking the problem of obtaining the highest diffractive productivity. Also obtaining phase and reflection holomasks is being attempted.

Judging from fast development of laser technology, one can expect the appearance on the market of lasers with appropriate power, (several hundred Watts,) working within the scope of spectral sensitivity of photoresists.

The problem of power of lasers is tied not only to question of reproduction, where the goal is to decrease to the minimum the time of the exposition of a layer of photoresists in order to insure the process of projection from vibrations damaging sharpness of reproducing. Also the process of creating holomasks matters. During holographing matrixes of holomasks and during reproducing the laser must work in the mode TEM_{00}. In this case distribution of the intensity of a laser beam has Gaussian, (i.e. normal, Tr.) character, (Fig. 4.) For the purpose of a uniform illumination of the entire indispensible field of vision the beam must be appropriately widened which causes the energy used effectively to diminish several times.

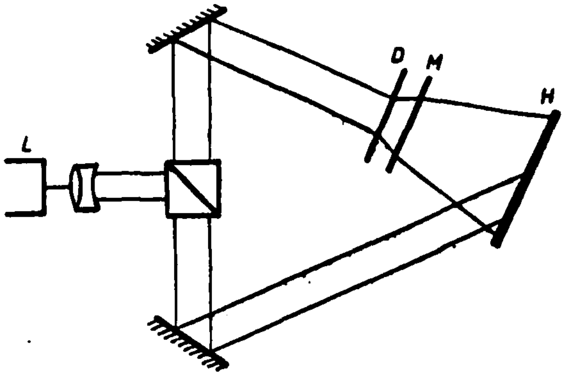


Fig. 5. An ideal scheme of a holographic system J.M. Beesley:
L - a laser, D - diffusor, M - a matrix of a holomask,
H - the hologram

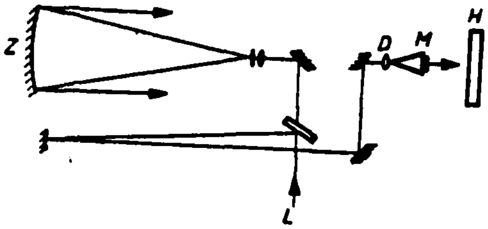


Fig. 6. A working scheme of a holographic system used by
J.M. Beesley: L - an Ar laser, Z - the mirror

The problem of widening the laser beam appears also when we are trying to illuminate the matrix of a micromask (Fig. 2.) with a wave with a flat phase front. For it is known that the phase front of a laser beam TEM_{00} has the radius of the curvature $R \neq 0$ So, in order to obtain a locally flat wave in the plane of the micromask M, the beam needs to be appropriately widened.

In the area of the discussed applications of holography J.M. Beesley [2] conducted investigations which already today have reputation of classics. (Fig. 5 and 6.) For production and reproduction he used an Ar (λ=488nm) laser with

Fig. 7. Reproduction obtained by J.M. Beesley (magnified): One can observe a characteristic increase of noises (spots in relation) to the information signal - "de-sharpening"; decay of small details.

with the line width $\Delta\nu$=2500MHz which initially limits distributive capacity to .2 µm. He used a wave with a flat front with an accuracy of around 1/4 λ which he obtained from a laser beam using an astronomical parabolic mirror Z with a diameter 2.4 and focus of 14.6 m. In the focus of the mirror with the accuracy of Δf=.4mm he was placing a screen lense with a tiny hole which served for so called spatial filtration for the purpose of obtaining a "pure" beam. He was illuminating the matrix of the micromask through the diffusor D. The Kodak HR

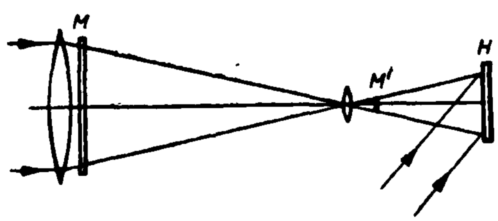


Fig. 8.A scheme of a holographic system used by H. Kiemle. M - a matrix of the micromask, M' - the picture of the matrix of the micromask, H - the hologram.

photographic plate was placed in a special fastener exactly on the optic axis and normally in respect to the reference beam. The distance between the matrix

and the plate was 10 cm. The holomask he had obtained, he reproduced with the same front of the wave.

Under such conditions J.M. Beesley obtained a good reproduction of a matrix containing 32 repeating elements constructed out of strokes 4 to 40 µm thick. The entire picture os covered with spots characteristic for a jointed illumination of a matrix by a diffusor. J.M. Beesley used diffusive illumination of the object - slide type, which has been already introduced by Leith and Uptanieks for the purpose of uniform scattering of informations about each fragment of the pattern (6), and for obtaining linearity of the record of the photosensitive material. It turns out, however, that in the case of holographing of micromasks diffusive illumination fails. Spots blur contours of reproduced patterns and make impossible reproducing its particular small elements. (Fig. 7.)

Pictures reproduced from holomasks lacking characteristic spots connected to illumination through an opalescent filter (diffusor) were obtained by H.Kiemle who is connected with Siemens company (5) using holographic system with a diffusor in the beam illuminating the matrix of the micromask. (Fig. 8.)

In his work the matrix encompassed only one module of an integrated circuit. He used creating a holomask from large patterns projected with the aid of an optic system, so that appropriately diminished picture of a pattern was recorded on the hologram. For the photosensitive layer he was using plates Agfa Gevaert 8E70. For the reference beam he was also using a wave with flattened phase front with a diameter 5 times larger than the hologram. Owing to this he achieved quite a faithful reproduction of one module of an integrated circuit. (Fig. 9.)

H. Kiemle himself during the discussion at the conference in Glasgow in 1970 (5), stated that his method deprives the process of holographing of a significant part of advantages of holography. If we bypass the problem of the dispertion of informations on the entire hologram, the problem of non-linearity of the record appears, for the diffractive-informative picture of a pattern in a plane of a hologram encompasses a high scope of optic densities. On reproductions of holograms characteristic diffractive streaks were appearing which were running along the edge. For reproduction he built a special revolving manipulator serving for precise olacing the holomask in respect to the reproducing beam. The quality of the reproduction was very sensitive to the position of the holomask. Nevertheless, the method

of the local recording of the information about the pattern of the holomask proposed by H. Kiemle is currently the most promising one and the work conducted by the holography laboratory of the Insitute of Physics of Warsaw Polytechnic and also by other centers refers to his method.

In the Institute of Physics of Warsaw Polytechnic until now holograms of whole matrixes of micromasks with dimensions 35 X 35 mm and with the average number of modules being 1000 were obtained. In the applied system of holographing the matrix of the micromask was illuminated non-diffusively by a divergent wave,

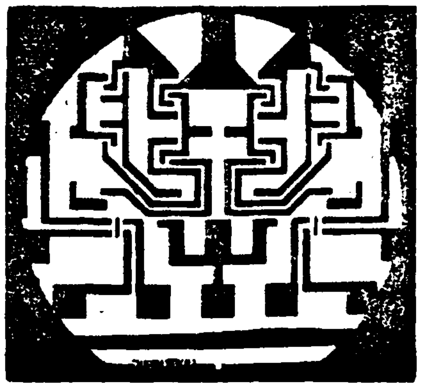


Fig. 9. A reproduction (magnification)of one module of a micromask obtained by H. Kiemle; dimensions of the smallest elements are approximately 10 nm.

or - wave with a certain divergence. Contrary to the Kiemle's system there are no optic elements between an illuminated matrix and the photographic plate of the hologram. Since such elements would be transforming the diffractive-interferentive picture of the micromask, they would have to have a very good correction. In the plane of the hologram we registered diffractive-interferentive pattern of the individual elements of the master copy originating from the luminous field bent on the matrix. That interferentive-diffractive fields interfers in the plane of the hologram with the reference beam, thus giving the holomask.

Such a hologram could be called a local hologram. To each element of a master copy refers a limited area of the holomask. Because of that for reproduction of such a hologram its entire area has to be illuminated, so that the reproducing

luminous field could encompass all of the local holograms.

The difficulties observed by Kiemle and connected with the spread of the intensities of holographically registered diffractive-interferentive beams, can be overcame by the appropriate selection of the intensity of the reference beam.

Even in local holograms noises in a shape of small spots can overlap with a sharp picture of a micromask. It is connected to the fact that the laser light with a large coefficient of consistence which used for production and reproduction is a subject of diffraction on all even on very small diffusing centers: On dust particles, nonuniformities of the glass basis of the master copy of the micromask during its production, and in the process of reproduction also on nonuniformities of the photosensitive substance on which the hologram has been recorded, etc.

Mutual interference of waves sent from diffusing points causes formation of accidentally distributed light and dark spots. Thus all the accidental, unwanted centers of diffusion which are in a holographic system, even with the size comparable to the length of the wave of the laser light used for the production and reproduction of the holomask fulfill the role of a peculiar, but harmful diffusion. All of the holographic systems of a holomasker have to be placed in dustless chambers; the number of used optic elements has to be reduced to an indispensible minimum; they have to have a high-level cleanness and optic uniformity.

As far as aberrations are concerned, holographic masking - in comparison to projective lense masking which requires very good optic systems, but whose excellence is limited - can be to a significant degree free from aberrations. Nevertheless, even in case of holomasks, all efforts have to be made both in the process of production and reproduction in order to remove deformations of the picture. It depends upon the excellence of the optic elements which are used, above all, for forming the beam illuminating master copies of a micromask, reference beam, and a reproducing beam. A hologram carries both phase and amplitude information. An information of a reference wave and of a reproduction wave overlap with the information about the pattern of the micromask. They can disturb faithfulness of the reproduction. The condition of a faithful reproduction of the shape of a pattern is the equality of phases if interfering luminous fields which make up the holomask and the reproducing luminous field.

In practice it requires a careful selection of phase fronts of producing and and reproducing beams. What would matter in an ideal holomasker would be a construction of such a hologram which would be least sensitive to the phase front of the reproducing beam.

A holomasker used in practice would consist of a central instrument serving for creating masks and of holographic projectors of masks arranged in production sections. Under such working conditions the maintenance of the ideal correspondence of phase fronts of a producing and reproducing wave is practically impossible. It appears that local holograms create a possibility of solving that problem.

Holographic Multiplication

Holography also creates possibilities for multiplying pictures which can be used in the technology of microelectric masking. Currently, in the

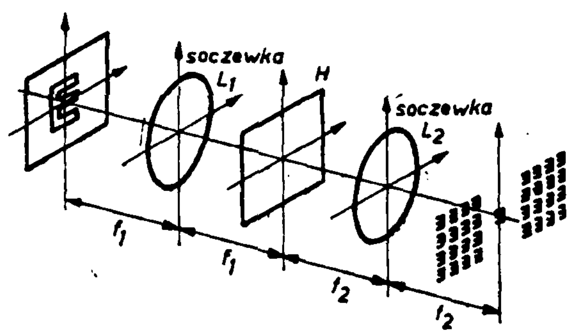


Fig. 10. A holographic system multiplying a picture with a Fourier hologram according to S. Lu, using the operation of so called filtration of spatial frequencies realized by coherent optic systems: H - a hologram, L_1 and L_2 - lenses

technology of microelectronic photolithography of a mask containing scores and hundreds of repeating identical patterns, a repeated exposure of one pattern is being made with tha aid of manipulators with the programmed steering. We have mentioned already attempts to multiply one module of a micromask in one exposure with the aid of a pulti-lense "eye of a fly". For purposes of masking

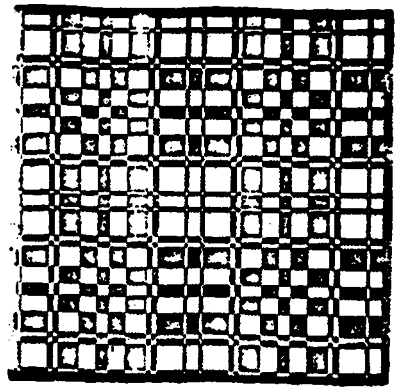


Fig. 11. So called binary synthetic hologram for multiplying pictures according to H. Damann.

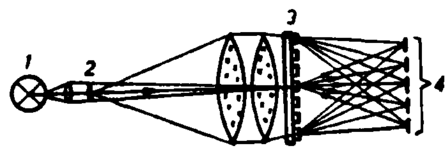


Fig. 12. A scheme of a method of an application of a synthetic multiplicatory hologram replacying the "eye of a fly" according to Damann: 1 - the source of light, 2 - the module of a mask, 3 - multiplicatory hologram, 4 - multiplied pattern of the mask

two systems of holographic multiplying are suitable:

*The use of a hologram instead of the already mentioned complicated optic "eye of a fly" system. In this case such a hologram is obtained:

- By methods proposed by G. Groh (8), and S. Lu, (7) which approximate each other and which consist of holographing of a system of microsources

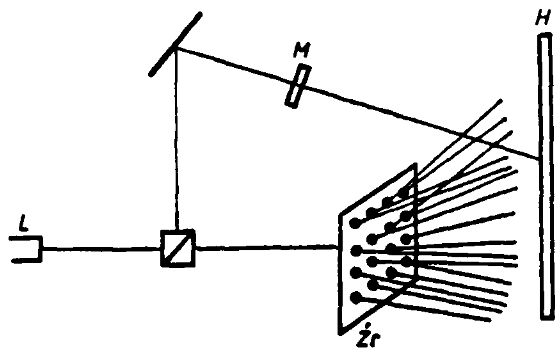


Fig. 13. A scheme of a multiplicatory holographic system according to A. Kalestynski. L - a laser, M - a matrix of a module of a micromask, H - a hologram Zr - the multibeam source.

which form a square or a rectangular net. The microsource are here microlenses of high quality. (Fig. 10).

- By the method proposed by H. Damann (10) which consists of producing a so called synthetic hologram which basically also fulfills the function of an "eye of a fly". A synthetic multiplicatory hologram, (Fig. 11) is obtained with the aid of a mathematical machine which draws a pattern of a hologram according to na appropriate program. The obtained hologram isso called phase binary or amplitudinal (tonal), consisting of a system of elementary holograms basically fulfilling a function of Fresnel lenses. (Fig. 12).

*Multiplicatory holographing of one micropattern by the use of many reference beams - by the method proposed by the author (11). The use of many reference beams (Fig. 13) allows to distribute a duplicated elementary pattern not only in the flat net, but also in spatial nets which creates possibilities of localizing microelectronic pattern in various depth of a crystal. In future it could be applied in the processes of diffusion steered by light limiting the scope of application of masking.

Other Applications of Holography in Microelectronic Industry

Holography can be also useful in investigating the quality of contact masks currently produced, above all for assessment of the accuracy of the arrangement of microsystems and their elements, deviations from anticipated shapes, smoothness of the surface of a micromask and of layers of photoresists (just like the smoothness of silicon plates.) In these problems the methods of holography can be helpful, namely double exposure which facilitate quick, non-contact, hence non-destructive comparison of a given specimen with an ideal master copy and mechanization and automatization of this process. Also, after after getting over earlier mentioned noises, it is possible to discover small interference of errors in the design of the micromodule. In this case methods of the analysis of the spectrum of spatial frequencies of the mask of the master copy can be helpful; the mask being studied with the aid of holographic, so called fitted filters of spatial frequencies Van der Lugt type (11), used successfully in optic correlators.

Closing, the author would like to express his thanks to Dr. Barbara Smolinska from the Institute of Physics at Warsaw Polytechnics for the help and critical discussion of the above elaboration.

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